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INFLUENCE OF IONS ON THE PASSAGE OF LOW FREQUENCY ELECTROMAGNETIC WAVES THROUGH THE IONOSPHERE

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SUMMARY

This paper is the generalization of the rigorous solution obtained in ref. [1] by the present author, on the passage of VLF electromagnetic waves through a planostratified magnetoactive ionospheric plasma in case of longitudinal propagation. Here the influence of ions is taken into account and the results are applicable in frequencies < 1.5 kc/sec.

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* *

Under the conditions of ref.[1] the angle between the wave vector and the direction of the magnetic field is zero and the magnetic field is perpendicular to the layers. When integrating the wave equation in [1], the expression for the complex index of refraction was borrowed from [1], in which the motion of molecules and ions was not taken into account. This is why all the calculations were conducted in frequencies f $\geqslant$ 1.5 kc/sec, knowingly satisfying the condition $\omega \gg \Omega_H$ (Ω_H being the gyrofrequency of ions), for which the influence of ions is immaterial.

In the current paper we bring forth the results of an analogous problem taking into account the influence of ions. We used for the initial expression of the square of complex index of refraction the formula obtained in ref.[2] for the case of longitudinal propagation and taking into account the motion of positive ions and molecules:

$$(n - j\varkappa)^2_{1,2} = 1 + \frac{(\omega_0^2/\omega^2)(1 + \nu_{im}/a)}{\left(\pm\frac{\omega_H}{\omega} - 1 + j\frac{\nu_{ei} + \nu_{em}}{\omega}\right)\left(1 \pm \frac{\Omega_H}{\omega} + \frac{\nu_{im}}{a}\right) + j\frac{m}{M}\left(\frac{\nu_{em}}{a} \mp \mp\frac{\omega_H}{\omega}\right)\left(\frac{\nu_{ei}}{\omega} + \frac{\nu_{em}\nu_{im}}{a\omega}\frac{N}{N_m}\right)}, \tag{1}$$

(*) O VLIYANII IONOV NA PROKHOZHDENIYE ELEKTROMAGNITNYKH VOLN SVERKHNIZKOY CHASTOTY CHEREZ IONOSFERU/

where

$$a = \omega\left(\frac{\nu_{im}}{\omega}\frac{N}{N_m} + j\right); \quad \Omega_H = \frac{m}{M}\omega_H;$$

$\omega_0 = \sqrt{4\pi e^2 N/m}$ is the plasma frequency; $\omega_H = eH_0/mc$ is the electron gyrofrequency;

$$\nu_{ei} = \frac{2{,}8N}{T^{3/2}}\ln\left(324\frac{T}{N^{1/3}}\right) \tag{2}$$

is the number of collisions of electrons with the ions;

$$\nu_{em} = 3{,}21\cdot 10^{-10}\, N_m\sqrt{T} \tag{3}$$

is the number of collisions of electrons with molecules;

$$\nu_{im} = 8{,}54\cdot 10^{-10}\, N_m\sqrt{T} \tag{4}$$

is the number of collisions of ions with molecules; N is the concentration of electrons; N_m is the concentration of molecules e and m are the charge and the mass of the electron; M is the mass of molecules and ions; T is the elecron temperature (assumed equal to that of heavy particles). As is shown in [2], the additional influence of negative ions on the value of the complex index of refraction may be approximately taken into account by substituting N in (2) by N_i, where $N_i = N_+ + N$ is the aggregate concentration of positive and negative ions. Introducing the coefficient $\lambda = N_-/N$, (usually determined in an empirical manner), we shall obtain for N_i

$$N_i = (1 + 2\lambda)N. \tag{5}$$

If we postulate in (1) $m/M = 0$, that is, if we neglect the influence of ions, we shall obtain for the square of the complex refraction index the expression utilized in ref. [1]:

$$(n - j\varkappa)^2_{1,2} = 1 + \frac{\omega_0^2/\omega^2}{\pm\,\omega_H/\omega - 1 + j\nu_{э\phi}/\omega},$$

where $\nu_{э\phi} = \nu_{ei} + \nu_{em}$.

The integration of the wave equation with the accounting for the influence of ions was conducted in the altitude range from 50 to 200 km in the daytime model of the ionosphere and in the 75 to 200 km for the night model in the frequencies from 50 cps to 5 kc/sec by the method proposed in ref. [1]. Inasmuch as the ordinary wave does not seep through the ionosphere in the VLF band, the calculation was performed only for the extraordinary wave (index 1, upper sign in formula (1)). The value of $(n - j\kappa)^2$ was computed by formulas (1)-(4). The dependences of electron and molecule concentrations on altitude, utilized in calculations, are plotted in Fig.1. The dependences N(z) differ little from those brought up in ref. [3, 4]; the curve $N_m(z)$ was borrowed from ref.[2]. The graphs of the dependence of electron temperature and ratio m/M on altitude (Fig.2) are constructed on the basis of data brought out respectively in [5] and [3].

The values of the reflection factor R (i. e., of the ratio of the wave amplitude, reflected from the lower boundary of the ionosphere to that of the incident wave) and of the transmission factor D, which constitutes the ratio of time-averaged value of energy flux for the passed wave to the corresponding value of the flux for the incident wave) were computed by formulas (6), (18) of ref. [1].

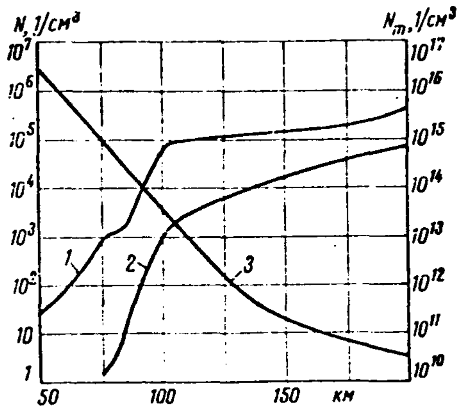

Fig.1. Dependence of electron concentration (1 — for the daytime model of the ionosphere, 2 — for the nighttime model) and of molecules (3) on the altitude

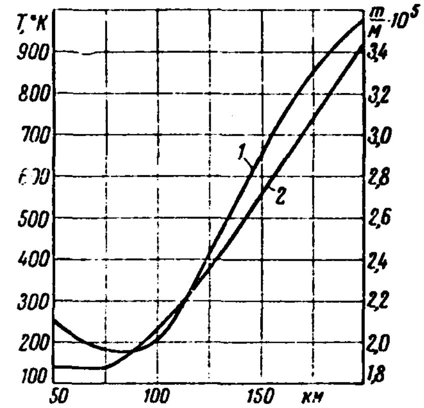

Fig.2. Dependence of electron temperature (1) and of ratio m/M on altitude

The obtained dependences of the transmission factors (at 200 km altitude) on frequency are plotted in Fig.3. As may be seen from the diagram, the quantity D for the daytime model of the ionosphere has a clearly expressed maximum in the neghborhood of the frequency f = 300 cps. On either side of the maximum the transmission factor decreases comparatively rapidly: at 50 cps, D = 0.04, and at 5 kc/sec D ≈ 0.015. The value of the transmission factor for the night model of the ionosphere decreases monotonically with frequency decrease from its maximum value D ≈ 0.8 in the frequency of 4 kc/sec to 0.1 in the frequency of 50 cps. It is necessary to note that the results of calculation brought out here for the transmission factors and obtained by way of rigorous solution of the wave equation, differ substantially from those obtained in ref. [4] in geometric optics approximation.

The results of calculations of the dependence of reflection factor's modulus on frequency are plotted in Fig.4.

In order to estimate the influence of positive ions on the values of the transmission and reflection factors, the wave equation was integrated without their being taken into account and with the utilization of formula (6) for $(n - j\kappa)^2$. The calculations completed have shown that the dependence of $|R|$ on frequency does not then practically vary in the entire frequency range 50 cps-5 Mc/s. At the same time the positive ions exert a small influence on the quantity D in the frequencies f < 1 kc/sec.

The influence of negative ions on the transmission and reflection factors was also verified. The experimental values of parameter λ, characterizing the concentration of negative ions in the lower ionosphere, were borrowed from ref.[6]. (See Table hereafter).

TABLE

	Daytime ionosphere model					Nighttime ionosphere model		
Altitude above ground, km	50	58	68	76	83	75	87	101
λ	56	10	1	0.1	0.01	10	1	0.1

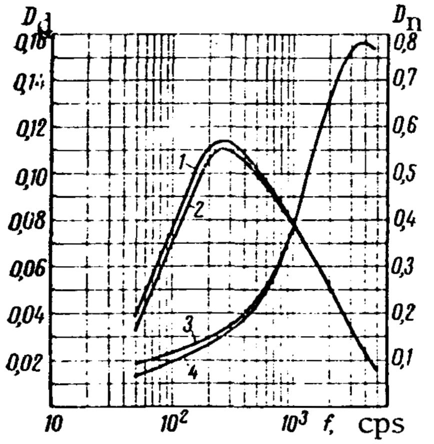

Fig.3. Dependence of the transmission factor on frequency for the daytime (D_d, 1) and nighttime (D_n, 3) models of the ionosphere. The curves 2 and 4 are obtained without accounting for the effect of positive ions

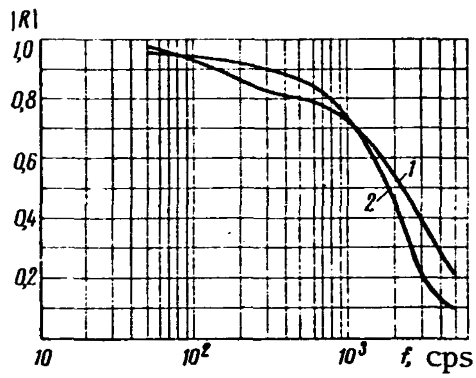

Fig.4. Dependence of the modulus of the reflection factor on frequency for the daytime (1) and the nighttime (2) models of the ionosphere

The calculations performed have shown that the negative ions do not practically affect the values of D and |R|, obtained without their being taken into account in the entire frequency band considered. This fact is in good agreement with the results of ref. [4]. in which it was noted that the accounting for negative ions does not affect the values of n and κ, even at those heights of the ionosphere, where their concentration is maximum.

**** THE END ****

R E F E R E N C E S

1. V. I. AKSENOV. Radiotekhnika i Elektronika, 11, 6, 1030, 1966.

2. V. L. GINZBURG. Rasprostraneniye elektromagnitnykh voln v plazme (Propagation of Radiowaves in a Plasma)., GIFML, 1960.

3. J. A. RATCLIFFE. Fizika Verkhney Atmosfery (Physics of the Upper Atmosphere). IL (Foreign Literature), GIFML, 1963.

4. D. S. FLIGEL', Geomagnetizm i Aeronomiya, 2, 5, 886, 1962.

5. T. K. BREUS, G. L. GDALEVICH. Kosmicheskiye Issledovaniya, 3, 6, 877, 1965.

6. Raspredelniye elektronnoy kontsetratsii v ionosfere i ekzosfere (Distribution of electron concentration in the ionosphere and exosphere). p.132, Izd-vo "MIR", 1964.

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